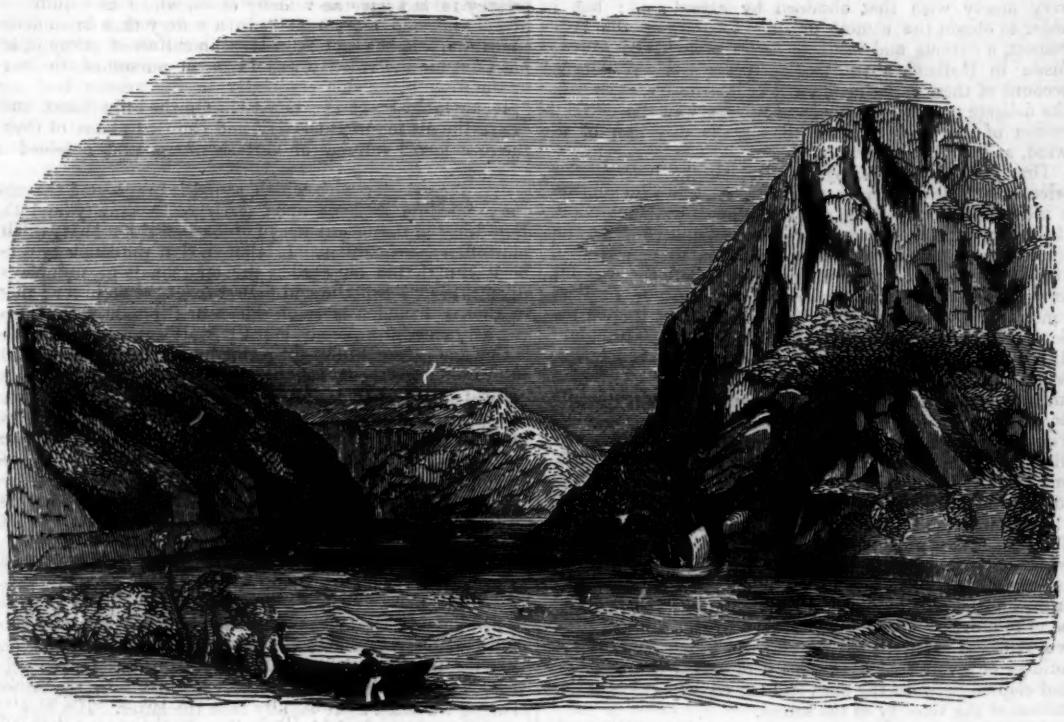
THE

Saturday Magazine.

No. 641. SUPPLEMENT, JUNE, 1842. Price One Penny.

THE PHILOSOPHY OF THE EXTERNAL SENSES. III.



THE ECHOING ROCKS OF LURLEY.

ON THE PROPAGATION AND CONDUCTION OF SOUND—MUSICAL SOUNDS—THE REFLECTION OF SOUND—RESONANCE AND SYMPATHETIC VIBRATIONS.

In the Supplement for April, we presented a general view of the nature and sources of sound, showing the various modes wherein the atmosphere may receive that peculiar disturbance which, when communicated to the ear, constitutes sound. We now take up the inquiry at that point, and proceed to consider:—

1. The Propagation and Conduction of Sound.

The manner in which a stretched cord vibrates has been explained in a former section; but the effect which that vibration exerts on the surrounding air has been purposely left undescribed till the present section, to which it properly belongs. When the motion of the vibrating cord commences, a layer of aërial particles, in contact therewith, must be urged forward by the impulse, and be pressed closer to a second layer or stratum contiguous to it. This approach is resisted by the natural elasticity of the air; but the impulse from the moving cord is too powerful to be wholly counteracted thereby, and the second layer or stratum is driven forward by the first: a new disturbance is thus created; for the second layer of particles urged onward by the first, presses on a third, the third on a fourth, and so on, each layer becoming, in its turn, a moving power to the layer next beyond it. If instead of a tended cord, we employ a drum or a plane surface of metal or glass, the principal difference in the result is, that more particles are set in motion at one time; but the impulse is communicated from particle to particle in the same way as if a stretched cord were employed.

As the atmosphere consists of particles of air readily acted upon by each other, the impulse travels onward with great rapidity; but the precise measure of this rapidity has been a very difficult inquiry in the hands of philosophers. There are two circumstances which regulate the velocity of this propagation, viz., the specific gravity of the air, or the weight of matter included within a given bulk, and the elasticity or resistance to compression. It was long ago determined theoretically, that as these two conditions or properties differ in different substances, the propagation of a sonorous impulse should be effected with different velocities in different cases; and this has been found true in experiment.

Sir Isaac Newton, from calculations in which the specific gravity and the elasticity of the air were taken as elements, stated the velocity of sound to be 946 feet per second; by which is to be understood that the disturbance of particles spreads so rapidly as to extend to a distance of 946 feet in one second of time. This assumed velocity, however, was found to be smaller than that deduced from carefully conducted experiments. From investigations made by Derham, Pictet, and other philosophers, at different hours of the day, and in different latitudes, it was found that sound travels at the rate of about 1130 feet per second. This discrepancy between theory and observation threw much obscurity over the subject, until Laplace brought his powerful mind to the consideration of its probable cause. It has been demonstrated that a change in the pressure of the air would not produce any change in the velocity of sound, because the more the density of the air is increased, the greater does the elasticity become; so that in rarefied air and in condensed air, provided *temperature* could remain the same, the velo-

city of sound would be uniform. But it occurred to Laplace, that the temperature of the air must exert a great effect; by an increase of temperature the air is expanded and rendered less dense, while the elasticity which it loses by that expansion is restored by the increase of heat; so that we thus have an equal elasticity and a less density, the two elements which give an increased velocity to the propagation of sound. A given quantity of air expands $\frac{1}{213}$th of its bulk with an increase of 1° of Fahr. in its temperature, a rate of expansion which makes the velocity of sound much greater in a warm than in a cold state of the atmosphere.

When the effect of temperature was taken into account, it was found that the theoretical velocity of sound agreed very nearly with that obtained by experiment; but in order to obtain the utmost possible accuracy in the latter respect, a curious and valuable series of experiments was made in Holland, about twenty years age. A detailed account of these experiments will be instructive, as showing the delicate precautions rendered necessary in the determination of the temperature of the air, the direction of the wind, and the humidity.

Drs. Moll and Beek, who undertook the investigation, selected two elevated spots near Utrecht, one of which was a hill called Kooltjesberg, and the other a similar hill near the village of Amersfoort. The two hills were visible one from the other, and the distance between them was about 18,000 metres (about ten miles). As it was necessary to measure seconds very accurately, time-keepers of a delicate construction were provided at each station, and their action depended on the following principle. Light, although it does not move instantaneously in the strict sense of the term, occupies in its passage a portion of time too small to be measured in any terrestrial experiments, and may therefore be deemed to move instantaneously; whereas sound is known to require about five seconds of time to travel a distance of one mile. If therefore a cannon were fired on one hill, the flash would be seen at another sooner than the sound would be heard.

Such was the principle adopted in the present inquiry. Time-keepers were furnished on such a construction as to work only so long as the finger pressed upon a certain spring, so that when one of the observers saw the distant flash, he instantly pressed the spring and allowed the index hand to move; and when the report was heard, the finger was removed from the spring, and the index stopped; the number of revolutions of the index indicated the time that had elapsed between the flash and the report, which at once measured the velocity of the sound.

At each station were placed, besides the clocks here spoken of, a barometer to determine the density of the air, a hygrometer to measure its humidity, a thermometer for the determination of temperature, a wind-gauge to show the direction of the wind, and a telescope to view the distant station. At each station were also planted a twelve-pounder, and a six-pounder; and tents were provided for the experimenters and their assistants.

In order that the guns at both stations should be fired at the same instant of time, the following preparatory arrangements were made. At 7ʰ 55′ P. M. by the chronometer of Zevenboompjes, (one of the stations,) a rocket was fired at that station, which, on being observed at the other station, was immediately answered by a second rocket. This was the signal that on both stations everthing was ready. At 8ʰ 0′ by the chronometer of Zevenboompjes a cannon was fired at that station, whilst the observers at Kooltjesberg noticed with great exactness the time on their chronometer when the flash was seen. This was repeated at 8ʰ 5′, so as to enable the observers to determine exactly the difference of their chronometers, due to difference of longitude. By this determination they were able afterwards to fire their guns at precisely the same instant of time; the object being to have a double series of observation going on when the air was in the same condition as to temperature, &c. The exact correspondence in the firing of the guns was obtained in the following manner. At each station, an officer had the chronometer placed before him on a small table very near the gun; a non-commissioned officer or gentleman-cadet stood ready with the port-fire, near the touch-hole, and at the instant required, the officer holding the chronometer pressed the arm of the person who was to fire the gun, which went off at the very moment. With a little practice they were certain to fire the gun at any given second. For several successive nights the experimenters were deprived of some of the desired results, in consequence of the wind preventing the report of one of the guns from being heard at the other station; but the combined result of repeated observations gave for the velocity of sound, at a temperature of 32° Fahr. 1089¾ English feet per second.

It thus appears that, even at the freezing temperature, the velocity of sound, as determined by experiment, is 144 feet per second greater than that deduced theoretically by Newton; and as Laplace showed that the addition of heat would make such an augmentation in the elasticity of the air as to augment the velocity of sound $1\frac{1}{10}$ feet for every increase of temperature amounting to one degree, it gives 1125 feet as the velocity at 62°, a temperature selected for many scientific purposes.

The presence of aqueous particles in the air has a tendency to increase the velocity of sound, as an impulse is communicated more rapidly in a watery than in an aërial medium. It has been found that in the moist sultry plains of Cayenne the velocity was 1175 feet per second, the augmentation being due conjointly to the greater heat and greater moisture of the climate. On the other hand, some experiments made on the dry and elevated plains of Quito gave a lower velocity of vibration than that obtained in Europe.

As the velocity with which sound is propagated through any medium depends upon the specific gravity and the elasticity of that medium, it follows that the velocity differs in different substances. It is found that the elasticity compared with the density, is greater in a large number of solids, in all liquids, and in hydrogen gas, than in air; and a sonorous impulse is communicated through them more rapidly than through air. Thus, Mr. Canton estimated the elasticity of water at about 22,000 times that of air, while its density is only 800 times as great; and this gives a velocity of sound equal to 4900 feet per second; nearly five times as great as in air. From some experiments made on the comparative densities and elasticities of pure water, sea-water, tin, silver, brass, copper, iron, and wood, it has been deduced that if the velocity of sound in air be called 1, then the velocities in the other substances will be nearly as follows:—pure water 4·1, sea-water 4·7, tin 7·5, silver 9·0, brass 10·5, copper 12, iron 17·0, wood from 11 to 17.

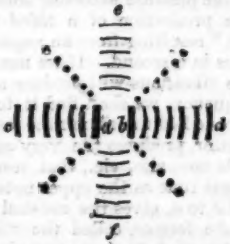
That sound travels with different velocity through different media has been abundantly ascertained. In some experiments performed by Biot on the water-pipes of Paris, when a sound was communicated at one end of a long tube filled with air, two sounds were heard at the other end, one having travelled through the mass of metal forming the tube, and the other through the contained air; the former having travelled more rapidly than the latter. If a blow be struck at one end of a brick wall, and a person apply his ear close to the wall at the other end, he will hear a duplication of the blow, first through the substance of the wall, and then through the surrounding air. It has been observed that when an earthquake has occurred near the sea-shore, the waves on the surface of the ocean, caused by the disruption, have been observed at a distant station in less than one-fourth of the time that a sound (such as a volcanic eruption) would have taken to travel that distance through the air. Sound travels through ice with about the same velocity as through water; and it is usual among the savage hordes who inhabit the sterile steppes of Tartary, where the intervention of lakes and the frequently frozen state of the ground give an icy character to the region, to place the ear to the ground on the expected approach of an enemy; thereby enabling them to hear more quickly, and to estimate more correctly the distance and the direction of any sound that might be sensible.

It is desirable now to offer a brief explanation respecting the state of the particles of air during the propagation of sound. When we say that sound travels 1125 feet in a second, it is not to be understood that any of the particles actually move to that distance; their individual movement is confined within extremely narrow limits, but the *effect* of this movement is propagated from particle to particle with the rapidity here indicated. As soon as the particles first disturbed have moved to such a distance as their elasticity will allow them, they return to their former position, and acquire in so doing a momentum sufficient to carry them to a short distance in the opposite direction; and thus they acquire an oscillatory or vibrating movement. Each particle receives its disturbing force later than the one preceding it; and thus the particles are in different stages of movement, some moving onwards, while others are moving backwards, the two sets being separated by particles occupying their original positions. This has given rise to the term, *wave* of

sound, a wave being understood to include particles in all the various stages of vibration, each wave being exactly similar to all the others. If we know the number of times that each particle vibrates to and fro in a second, we can ascertain the length of the wave of sound; for by dividing 1125 feet by the former we obtain the latter. The successive waves of sound have been beautifully illustrated by the analogy of a waving field of corn. Supposing the stems of corn to be vertically situated and to be equidistant, if a blast of wind were to blow over the corn-field, it would first influence those stalks nearest to the point from whence the wind comes, and they would be bent in the contrary direction. But by the time the impulse had been communicated to other stalks a few feet distant, those first disturbed would rear their heads again; and not only so, but they would acquire a momentum which would carry them to the other side of the vertical line. The resulting effect may be illustrated by the annexed cut, in which the points from *a* to *b* represent the ears of corn congregated more closely than in their quiescent position, while at other points they would be separated more widely asunder. If we suppose the elasticity of the stalks to be equable and uniform throughout, the distance from *a* to *b*, or a wave of undulation, would depend on the length of the stalk, and not on the violence of the wind; the principal circumstance which determines it being the rapidity with which the stalk would return to its quiescent position after disturbance.

When speaking of the distance to which a sonorous impulse is propagated in a second of time, we confined our remarks to a row of particles situated in a straight line; but in practice this limitation cannot be maintained. Any impulse which tends to urge one particle of an elastic fluid in a certain direction, cannot do so without exerting a lateral pressure on the surrounding particles; for the equalising tendency of elasticity renders impossible the forward motion of particles without at the same time disturbing the equilibrium of those situated laterally.

We shall attain greater accuracy if we suppose sound to be propagated spherically round the vibrating body. When an explosion takes place, the waves form a series of concentric hemispheres, since the surface of the earth may be considered as bisecting the spheres into which the waves would otherwise be formed; and in the absence of wind, we have every reason to believe that the sound is equally loud and travels equally far in every direction. But if we vibrate a string or a flat surface, we have no reason to expect the sound to be equally loud in every direction. If, for instance, a tuning-fork be vibrated, and held so that the plane of vibration shall pass through the ear, the percussion on the tympanum, or the loudness of the sound, (which are analogous expressions,) is greater than when the fork is held at right angles to that position. We may illustrate this by the annexed figure. Let *a b* represent the two prongs or arms of the tuning-fork, with their ends presented towards the eye; and let the concentric segments represent the circles or rather spheres of



undulæ which are in constant process of generation from the central point. The employment of segments of circles indicates that the velocity is the same in every direction; but the *thickening* of the segments from *a* to *c* and from *b* to *d* may be taken to indicate the greater loudness or intensity of the impulse at those points from *a b* to *e*, or from *a b* to *f*, on account of the vibrations of the parallel bars being performed in the direction *a b* to *c*, and *a b* to *d*. If the plane of vibration of a string were constant in its position, it is probable that we should find a different intensity of the sound elicited from it, according to the position in which the ear were placed with respect to that plane; but it is almost impracticable so to regulate the impulse given to the string as to confine its vibrations to one plane.

The circumstance which determines the distance to which sound can be propagated, is the intensity of the first impulse; and whatever that intensity may be, the effect upon the ear decreases as the square of the distance increases. But this rule remains permanent only when the sound is capable of a spherical propagation. If it be interrupted by any solid obstacle, those waves which would otherwise proceed in a straight line from the sounding body, are diverted from their original direction: they are reflected or carried along the surface of the obstacle, and extend to a considerable distance with very little loss of intensity.

A series of valuable and curious experiments on the effect of tubes in aiding the audibility of sound at a great distance were performed by M. Biot some years ago. He availed himself of the opportunity afforded by a combination of cast-iron pipes which had been newly laid down for the purpose of supplying the city of Paris with water. These pipes formed a continuous canal of equal internal diameter throughout, and had two flexures about the middle of its length. M. Biot, after stating that the pipes extended to a distance of 951 metres (about 3120 English feet), proceeds thus:—"Sounds uttered in the lowest tone of voice were heard at this distance, so as not only to enable me to distinguish the words, but to keep up a lengthened conversation. I wished to determine the lowest tone at which the voice ceased to be heard, but I was unable to do so: words spoken as low as when we whisper in another's ear were heard and appreciated; so that in order *not* to be heard there was positively but one means, which was not to speak at all. Between the asking and the answering of a question in this manner there elapsed $5\frac{5}{6}$ seconds; this then was the space of time that the sonorous impulse occupied in travelling twice the length of the column of air, that is, $951 \times 2 = 1902$ metres (6240 feet, about a mile and a quarter). In order to ascertain whether grave and acute sounds, or strong and weak sounds, were propagated with equal rapidity, or if there were under such circumstances any difference between them, I caused some airs to be played upon a flute at one of the extreme ends of the pipes. It is known that a musical piece is generally subject to a certain 'measure' which regulates very exactly the interval between the succeeding sounds. Consequently if some of the notes were propagated either more rapidly or more slowly than others, they would have arrived at my ear in a confused manner, the various tones mingling with those which preceded or followed them in the order of the tune, which, thus heard, would have been entirely changed in character. But instead of that, it was perfectly regulated in strict conformity with its natural time. Whence it results that all sounds are propagated with equal velocity." Biot states that in order to perform this experiment successfully, he found it necessary to choose the calmest period of the night, to avoid the interruption which the busy hum of day would have occasioned. He also fired a pistol at one end of the tube, and says that the report "occasioned a considerable explosion at the other end, when the shock arrived there. The air was driven from the last pipe, with sufficient force to produce upon the hand, the sensation of an impetuous wind, to hurl light bodies placed in its path, to a distance of more than half a metre, and to extinguish lighted tapers, although we were at the distance of 951 metres from the spot at which the pistol had been fired two seconds and a half before."

2. Musical Sounds.

The difference between a *noise* and a *musical sound*, and the diversities of the latter, are the points to which we next direct our attention.

A *noise* is the impression produced on the ear when the vibrations of the sounding body are irregular, whereas a musical sound owes its beauty to the regular and equal-timed vibrations of the body which yields it. If a body be struck and it produces a dull or a grating sound, we may generally conclude that it possesses little elasticity, or at least that it is not fitted for the performance of vibrations. Such is the case with a beam of wood, a clod of earth, a mass of stone, &c. But when, either from the nature of

the substance itself, or from the form into which it is worked, a body is capable of vibrating regularly, then the emitted sounds partake of that character which we are accustomed to call "musical."

Moreover it is found that when two bodies vibrate regularly, but one more rapidly than the other, the former yields a higher tone than the latter. An experiment made by Savart, a learned Parisian philosopher recently lost to science, will enable us to illustrate these points. He caused a metallic wheel to be made with 360 equidistant teeth cut in its edge; and held a piece of card in such a position as to be struck by every tooth in succession as the wheel revolved. Now the slip of card, not being of elastic material, was not calculated to vibrate either continuously or equably after percussion, and therefore a musical sound could not result from any one single blow. But if the wheel revolved so fast as to cause a large number of blows per second to be given to the card, then a musical sound was heard, not due to the vibrations of the card itself, but to those of the air moved by it at each blow. When the wheel was turned so that six or eight teeth struck the card in a second of time, nothing but a succession of slight blows was heard; but when the rapidity increased to sixteen, a low humming sound was distinguishable: the individual sounds lost their separate identity (so far as the sense of hearing was concerned), and became blended in a continual hum or low musical note. When the velocity of rotation was increased and the rapidity of contact between the teeth and the card thereby augmented, the sound, still continuing musical, was heightened in pitch, becoming more and more acute as the rapidity increased. Savart was thus enabled to attain a rapidity of 4000 strokes of the card in a second; and by a different form of apparatus he reached so high a number of 24,000 vibrations, which yielded a note of extraordinary acuteness.

If we inquire why the noise produced by the avocation of the itinerant knife-grinder is an unmusical one, it will not be difficult to show that it must result from that inequality of vibration before alluded to. The small elevations which cause the roughness of his grindstone are situated at irregular distances one from another; and the sounds resulting from the friction between those elevations and the blade of steel which he applies to the wheel, do not follow each other at exactly equal intervals. It is probable that if his wheel were cut across its edge with regular groves like a file, the sound would be somewhat musical, so long as the grooves retained their figure. We may similarly account for the grating, unpleasant noise of a saw, by considering the very unequal rapidity with which the arm moves. This unequal motion gives an irregularity to the rapidity of the concussions between the teeth of the saw and the object against which they strike.

We thus see that equability in repetition is the agent to which we are to look as the regulator of musical sounds, and we choose the materials of our musical instruments with especial reference to their vibrating quality. A glass goblet and a porcelain vessel of the same shape yield sounds different in musical character, not because one is harder than the other, but because one is more elastic and performs its vibrations more equably. The cords of stringed instruments are formed either of metallic wires, or of an animal substance which regains its primitive position after disturbance, with great regularity and intensity. Cymbals and bells are formed of a metal whose vibrations are both extensive in range and regular in recurrence. Wind instruments, which depend for their action on the longitudinal vibration of a column of air, derive their musical sounds from the circumstance that air is perfectly elastic, and thus performs all its vibrations in equal times. We thus arrive, by various paths, at the conclusion before stated, that all our musical instruments are merely contrivances by which the circumambient air may be set into equable and rapid vibration.

We have stated that if two musical notes be due to different velocities of vibration, the higher velocity produces the more acute tone. We have now to speak of a third sound resulting from the simultaneous production of the other two. When we put a string into vibration, every time it passes the axis or position of rest it gives one impulse to the surrounding air and to the ear. Suppose this to occur 100 times in a second, and that we take another string whose vibrations amount to 200 in a second; then if we vibrate both together, we cause two separate systems of undulations to be propagated, the one with a rapidity of 200, and the other of 100 in a second. Every second vibration of the former will coincide with one of the latter, and an augmented impulse will be the consequence. This augmentation of intensity, occurring at intervals of $\frac{1}{100}$ of a second, furnishes a new element, as if a *third* note were actually produced, equal in pitch to the lower of the two original notes.

But this will be rendered more clear if one of the strings vibrates 100 and the other 150. In such case we shall find every second vibration of the one coinciding in direction and in ultimate effect with every third vibration of the other; these coincidences would thus occur 50 times in a second, and would thus form a third series, springing from, but independent of, the other two.

It is from this source that many writers on Harmony trace the pleasure which results from musical sounds, that is, from the production of a third sound from two others heard together. We are aware that other theories have been offered in relation to this matter; but without entering on the controversies which the subject has excited, we shall offer such details as will serve to convey a few general notions on the matter.

If the performers on two musical instruments produce two dissimilar tones, or if a performer places his fingers on two keys of the pianoforte at the same time, and the united sound be pleasant to the ear, we shall always find that the rapidity of vibration producing those tones has such a ratio, that a third series, resulting from the coinciding intensities of the other two, will have a considerable rapidity of repetition. If the two series are equal in rapidity, the musical effect is what is called *unison*, which is the most perfect agreement of tone. If the velocity be as one to two, the latter is the "octave" to the former, the next approximation to unison. If they are as two to three, the one is (in musical language) a "fifth" to the other. If, on the contrary, we take any more complex ratio, such as eleven to seven, we should find that no musical interval is represented thereby. In what way this bears on the principles of harmony we shall endeavour to explain.

Every one is familiar with the expression "a musical tone" or "semitone," and there are but few individuals so entirely destitute of musical feeling as to be unable to produce a few notes of an air or song with an approximation to correctness. Now it is found that the notes sung or played or hummed by any number of persons, bear, within a comparatively small range, a close analogy to each, as regards the intervals between the notes; and this tacit agreement among both learned and unlearned well deserves our consideration.

In order to give precision to our remarks we will assume that a certain note, called C (*DO*) for instance, is due to 240 vibrations per second. In the standard tuning-forks used at Mr. Hullah's Singing Classes at Exeter Hall, the C or *DO* is taken at 256, 512, &c., vibrations per second; but our assumption is taken merely for the sake of avoiding fractions, and is not to be considered in any other light. If a tone, resulting from 480 vibrations per second, be heard at the same time as our assumed fundamental tone, the agreement is so perfect and satisfactory to the ear, and the new tone bears such a close resemblance to the fundamental tone, that it has been universally agreed to designate it by the same letter of the alphabet. We have then two tones (C and c) depending respectively on 240 and 480 vibrations per second; and the pleasure derivable from them has been attributed to the production of a *third* tone, called the "grave harmonic," resulting from an augmentation of tone repeated 240 times in a second. If we next estimate what ratio between the vibrations will produce a harmonic of the next greatest frequency, we shall find it to be the ratio of 3 to 2. 360 bears to 240 the same ratio as 3 to 2; and if heard with the latter, produces the very agreeable interval of the fifth. This note also, viz., that resulting from 360, if heard at the same time as the upper note 480, to which it bears the ratio of 3 to 4, gives the musical interval, almost as agreeable as the former, called the "fourth." In the same way the ratio of 5 to 4, a very simple one, gives a harmony very pleasing to the ear; and we find accordingly that 300 and 240 will yield this ratio.

We thus obtain four notes, which may be represented thus:—

C	E	G	c
DO	*MI*	*SOL*	*DO*
240	300	360	480

all of which are connected by very simple ratios, viz., C and c=1 to 2, C and G=2 to 3, C and E=4 to 5, E and c=5 to 8, E and G=5 to 6, G and c=3 to 4. These four notes produce

a beautiful effect when sounded together, and then form what, in musical language, is called the "common chord." An attentive ear is conscious of hearing many sounds besides those properly belonging to the four notes; these are the "grave harmonics," resulting from the frequent coincidences of the vibration of different notes, when the ratios between them are simple.

But the vacancies between these four notes are too wide for the purposes of music; and it has been the custom, in almost every country, to insert three others, so as to form a gradually ascending scale of sounds. The manner in which this has been effected is the following:— It will be seen that three of the above notes, C, E, G, have vibrations in the ratio 4, 5, and 6; this relation has been called a "triad," and two other similar triads may be so introduced as to fill up the vacancies in the scale. Let us make c the highest note of such a triad, and G the lowest note of another such; these will give respectively 320, 400, 480, and 360, 450, 540; each pair of which gives numbers in the ratio 4, 5, 6. As every note receives the same name as the note resulting from exactly half the number of vibrations, on account of the similarity of sound, we may take, instead of 540, its half 270; and then we can form our scale thus, affixing letters to the notes produced:—

C	D	E	F	G	A	B	c
DO	*RE*	*MI*	*FA*	*SOL*	*LA*	*SI*	*DO*
240	270	300	320	360	400	450	480

This forms the usual "diatonic scale" of music, of which the intervals appear so natural, that if an unpractised person be required to utter an ascending series of tones, he is found, involuntarily and in utter ignorance of the fact himself, to produce a succession of sounds the result of a series of vibrations very nearly in the ratio here given. As far as we are justified in referring this circumstance to its source, it would seem that this natural series produces a system of "grave harmonics," so rich and full as to appeal powerfully to the ear.

It is customary to distinguish between melody and harmony, on the ground that melody is a succession of single sounds, while harmony is a combination of sounds heard at one time. But, however correct this distinction may be, it is worthy of remark that every melody is made up of sounds so chosen with regard to each other, that different combinations of twos, threes, and fours, chosen from among them, produce those beautiful effects which we designate harmony. Melody and harmony, therefore, however different, derive their charm from the same common source, viz., a certain simplicity of numbers among the vibrations producing musical notes.

There is another point of view in which the ratios between the different notes of the musical scale may be considered, which is also convenient as enabling us to speak of the comparative lengths of a string which produce the eight sounds of the octave. It was stated in a former page, that a string, in order to vibrate with twice the velocity of another string, must be one half the length; to vibrate with thrice the velocity, it must be one-third of the length, and so on. It follows from this, that whatever ratio exists between the numbers of vibration producing any two given tones, the comparative lengths of two strings which produce those tones are in the inverse ratio. If we reduce the list of numbers, 240, 270, 300, 320, 360, 400, 450, and 480 to a similar series of which the lowest = 1, then the whole will be 1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{8}{15}$, $\frac{1}{2}$, 2; and if we invert the divisors and dividends of the fractions we obtain 1, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{15}{8}$, 2, 1. When, therefore, we have a string which yields the note C, due, as we are here supposing, to 240 vibrations per second, if it be shortened to $\frac{8}{9}$ of its full length, it will yield the next note D; if to $\frac{4}{5}$, the note E; and so on.

The whole of the details which have recently engaged our attention, relate to the tones of *one octave* only; but we shall find this quite sufficient for our purpose, as every successive octave is formed precisely in the same way. To ascertain the number of vibrations producing the tones in the next higher octave, we have only to double the numbers attached to the corresponding letter in the lower octave; for the second higher octave we take four times the number, and so on.

We assumed as a convenient number, 240 vibrations per second for the note C; but we also stated that 256 is the number now fixed upon in practice. On this latter point it may be well to offer a few words of explanation. It has been deemed convenient to call the effect produced by one vibration per second (although perfectly inaudible) by the letter C, and to apply the same title to all the duplications of that number, that is, to 2, 4, 8, 16, 32, &c., vibrations per second. It is found that, in following this series, the fifth C is, under ordinary circumstances, about the lowest sound which can be heard, and that the middle C of a pianoforte is the ninth in the series, due to 256 vibrations per second. This was the standard recommended by the late Dr. Thomas Young, and is one possessing many advantages; but in practice there has been great diversity. Experiments made at different times have shown that the middle C of the piano-forte has varied from 238 to 264 vibrations per second, in different orchestras and at different periods. To remove the obvious inconveniences resulting from this state of things, a standard has been recently determined whereby the middle C of the pianoforte shall be produced by 256 vibrations per second,—the number recommended by Dr. Young. The determination was, in the first instance, made with a view to the preparation of tuning-forks for the Singing Classes conducted by Mr. Hullah, at Exeter Hall, under the sanction of the Committee of Council on Education, the C selected being an octave above that just named, and being adjusted by scientific means to 512 vibrations per second; but the standard, once attained, is calculated for general use, both in instrumental and in vocal music.

The highest note used in music is about the 14th C (five octaves above the middle C of the piano-forte), due to about 8000 vibrations per second; but much higher tones can still be heard, although their very acuteness deprives them of all value for the purposes of music.

The earlier details of this section have given a sufficient idea of the nature of the "grave harmonic," and of the probable mode in which this harmonic heightens the effect of musical combinations. But the term harmonic has likewise been applied to tones produced under very different circumstances; tones which, from being always *higher* than the fundamental tones whereon their production depends, are called "acute harmonics."

If we draw a bow across the string of a violoncello about midway between its two extremities, we draw the central part farther from the position of repose than any other part; the consequence of which is that the whole string continues to vibrate backwards and forwards over the line of repose. But if the bow be applied gently near one end of the string, four tones can frequently be heard at once, three of which are called "acute harmonics." The origin of this singular effect seems to be, that while the whole string vibrates in one system to produce the fundamental or proper note of the string, it is at the same time broken up into three subordinate systems, composed of aliquot parts of the string. Sometimes these lengths are $\frac{1}{3}$, $\frac{1}{3}$, and $\frac{1}{4}$ of the whole length, and in such case the tones resulting from them are the octave, the twelfth or octave to the fifth, and the double octave.

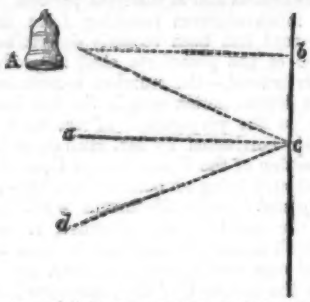
Much obscurity exists as to these subdivisions of a string. A writer in the *Encyclopædia Britannica* attributes their formation to the reaction of the fixed termini of the string; that is, that the string by its vibration communicates a vibratory impulse to the solids to which the two ends are attached, and that those vibrations are reflected, as it were, from the solid supports back to the string, and by interfering with the continuity of the previous vibrations existing therein, generate a new series of a different rapidity from the former. These harmonics can be artificially produced by placing the finger very lightly on any of the aliquot divisions of the string, and drawing the bow across near one end of it; in this case the two divisions of the string will vibrate in different systems, and will produce tones dependent on their relative lengths.

3. The Reflexion of Sound.

When an obstacle opposes the motion of an elastic body in any given direction, a rebound or reflex motion occurs, whether the moving body be a solid ball, waves of water, of light, or of sound. All of these present very similar features, in respect of the direction in which the impulse is communicated; but it will be sufficient to confine our attention here to the phenomena presented by sound.

Let us take, as a simple illustration, the case of a bell sounding at a short distance from a wall. Let *b c* be the wall, and A the bell, from which pulses of sound proceed in all directions, of which we will here take notice only of the two A *b* and A *c*. The pulse which proceeds perpendicular to the wall, A *b*, is reflected back along the same line; but the pulse A *c* is reflected, not along the same path, not perpendicularly to the wall, but in a direction *c d*, which is as

much below the line *a c* perpendicular to the wall, as A *c* is above it. This is expressed by saying that the "angle of reflexion is equal to the angle of incidence," a law which, by its applicability in optical phenomena, is productive of important consequences; were not this "equality of the angles" true, our mirrors would give distorted and irregular images of reflected objects; the reflecting telescope, the concave reflector of a microscope, the parabolic reflector of a lighthouse, all would produce irregular results; but the law is uniform and constant, both in sound and light.



When we consider that a circle is a line, of which every point is equidistant from the centre, we can easily comprehend that when an impulse, such as that of sound, is received from the centre, the reaction or rebound from the circumference follows precisely the same path as the original impulse, but of course in the opposite direction. Every part of the circle is perpendicular to the centre; and as the angle of reflection is equal to the angle of approach, when that angle is 90° or perpendicular, the reflection is likewise 90° or perpendicular, and the two paths coincide. Now if we pass from the consideration of a single impulse, to that of an impulse generating from the centre and extending in every direction, we shall easily see that the reflexions would all congregate at the centre of the circle, and a sound of extraordinary loudness would be heard by any ear placed at that point.

The effect of a circular obstacle being understood, it will not be difficult to apply the same principle to instances wherein the reflecting barrier is formed into any other geometric figure. For example:—One of the properties of the *ellipse* is, that there are two points or foci, more or less near the centre of the figure according to the proportions between its length and breadth, such, that two lines drawn from those foci to any given point in the curve shall form equal angles with the curve at that point. From this it follows, that if a sonorous impulse emanate from one focus of an ellipse,—say a brick wall formed into an elliptical shape —the reflected waves will all congregate at the other focus. If the ellipse we have employed were the wall of a racket or fives-court, and a player were situated at one focus, in whichever direction he struck or threw his ball, it would after reflexion, fall near the other focus. If it represented the raised border of a billiard-table, a ball propelled from one focus would rebound in the direction of the other. If it represent a series of mirrors arranged in an elliptical form, and a candle were placed in one focus, an eye at the other focus would receive rays of light from every part of the curved boundary of glass. These are exemplifications of the maintenance, in many different aspects, of the two laws relating to reflexion and the properties of the ellipse.

We will here give two instances to illustrate the effect of uttering audible sounds in the focus of an ellipse. There are on each side of Westminster Bridge several arched recesses (intended as resting-places), and placed exactly opposite to each other in pairs. If in the stilly calmness of night two persons place themselves in opposite recesses, with their backs towards each other, and one of them whisper, the other will hear distinctly what is said. These two recesses form the two ends of an oval or ellipse; the whisperer is situated at or near one focus, and the listener at or near the other; and the multiplied reflexions produce a sound as loud as if the listener's ear were close to the speaker. The other instance is the following. There is a church in Italy wherein the two ends are elliptically formed, and the confessional (common in Roman Catholic churches) happened to be in one focus of the ellipse. It chanced on one occasion that two persons were present,—one in the confessional, in the one focus, and the other near the other focus,—and the latter heard the recital made by the former. The consequences were such as were unpleasant to all parties, and the confessional was thereafter removed to a different part of the church.

If the preceding details be clearly understood, we shall be prepared to expect that an irregularly-formed surface would reflect sound irregularly, and without any tendency to focalization; and this brings us at once to the cause of the great varieties of *echoes*.

The poetic fervour of the ancient Greeks, and particularly their fondness for personifying the feelings, the passions, and even the perceptions, were excited by the mysterious and captivating nature of echo. The laws which regulate sound were not sufficiently understood to enable the philosophers of those times to assign the true origin of echo. They therefore depicted it as "a lovely nymph, doomed to wander in wild and lonely places, and to *repeat* the language of others." When however advancing science broke the poetic charm which the warm imaginations of the ancients had thrown around this as well as many other natural phenomena, it was then clearly ascertained that echo is merely the result of reflexion of sound, chiefly, but not always, from solid obstacles.

If a person were standing on a rocky eminence, and a surface of wall were immediately opposite to him, a sound, when uttered by him, would, after reflexion from the opposite surface be remitted to the spot whereon he stood; and the time which would elapse between the utterance and the reception of the echo would depend altogether on the distance between the two stations. If, as before shown, sound travels at about 1125 feet per second, and if the distance between the stations be half a mile, the interval of time between the sound and its echo would be about 4⅔ seconds. As a converse problem we may suppose that the elapsed time is 3¼ seconds, and may ask how far asunder are the stations. Easy calculation shows this to be about 2110 feet. If the two stations be so situated that a second wall or smooth rock is immediately behind the speaker, and exactly opposite to the first, there will be a repetition of echoes, the sound reciprocating backwards and forwards.

These multiple echoes lead us to a remarkable and instructive inquiry, viz., the gradual production of a musical tone as the distance between the stations decreases. If the two stations were 562 feet apart, the speaker would hear his voice echoed once every second until the sound finally died away; if the distance were 140 feet he would hear four echoes per second; and if 35 feet, the echoes would occur sixteen times in a second. Now it will be recollected that, when treating of musical sounds, we stated that a sound *of any kind*, repeated regularly and equally 16 times in a second, constitutes a nominal note, nearly the lowest which the ear is capable of appreciating. In the instance of echoes, therefore, when they occur less frequently than 16 in a second, the ear can detect and appreciate them singly; but when they are more frequent, their separate identity becomes lost, and the whole blend into a deep musical tone. When the distance between the stations is reduced to about 13 feet, the echoes occur with a rapidity of 43 in a second. Now a sound repeated 43 times in a second produces a tone equivalent to the lowest F of the piano-forte, and the person who utters the sound would find that he was accompanied, not by a succession of echoes, but by a low musical note.

These considerations enable us to explain a circumstance not always well understood, viz., the tone or sound heard in an empty room. If a room be well and squarely built, the sides unbroken by recesses or projections, and destitute of furniture, a constant and unvarying *tone* will follow any sound produced therein, and that tone, in regard to pitch, will depend on the size of the room. It is also presumed that the speaker is in the middle of the room, midway between either two opposite walls. Let us suppose the room to be 16 feet long. A sound uttered by a voice in the centre of the room would travel 8 feet, to reach one wall, from which being reflected it would again travel 8 feet, and then reach the ear. The impulse, meanwhile, would have produced a similar effect in the opposite direction, and both echoes would reach the ear at the same time, after having travelled 16 feet. But this would not stop the progress of the impulses; they would be reflected from side to side, until the force was gradually expended. As each pulse of sound would impinge regularly on the ear, after having travelled 16 feet, it follows that the ear would be excited by the sonorous vibrations existing in the air 70 times per second, because 1125 feet (the velocity of sound per second), divided by 16 (the distance travelled by each echo) gives about 70. An impulse repeated 70 times per second gives the note D, two octaves below the middle D of the piano-forte, and we

should be justified in saying that the *tone* of that room is the note in question. In the same manner we may ascertain the tone belonging to any room, by taking the velocity of sound at 1125, the number of vibrations producing the middle C of the piano-forte at 256, and combining these results with the dimensions of the room.

When we produce a sound of moderate loudness in a vaulted passage, the concavity of the ceiling concentrates a large number of reflexions at the centre of the passage, and the great rapidity of the echoes from side to side produces a musical tone having considerable elevation of pitch. These two circumstances combined, produce extensive and remarkable modifications in the original tone. It is with difficulty that two persons can understand each other when speaking in such a passage, because the accumulated echoes and the resulting musical tone, mingle with the next following words. This circumstance renders it desirable to make a distinction between the interior fittings of a room intended for oratory, and those of one intended for music. In the case of music a slight echo is far from disagreeable, because it augments and enriches the sound, especially in slow movements, where there is time for the echo to perform its part before the next note is played. In a room intended for oratory or conversation, however, echo is decidedly bad. The object of the speaker is to be well understood by his hearers; but if the echo of his first word mingles with the original sound of the second, the former becomes confused and difficult of appreciation: and this inconvenience will increase whenever the speaker increases the rapidity of his utterance. This has been assigned as one reason, among others, why so much of the cathedral service is chanted, or expressed in musical tones; the resulting echo not being so inconveniently felt under such circumstances.

The production of a musical note by the regular recurrence of echoes, is pleasingly shown by striking one end of a row of iron-railings placed equidistant. When we strike the first bar, the air between it and the second will be set into vibration, and will be reflected from the surface of the second bar. Another portion of the impulse will have been travelling onward toward the third bar, from which it will in like manner be reflected. A third instant of time will witness the approach and rebound of a third portion of air at the fourth bar: and so of all the others. Now the resulting effect is curious. Let us suppose the bars to be eleven inches apart and one inch thick; we shall then have one foot as the distance between the corresponding sides of two contiguous bars. When therefore the first bar is struck, the impulse has to travel two feet before it again reaches the first bar, that is, one foot before and one after the reflexion at the second bar: now to do this it occupies $\frac{1}{1125}$ or .$\frac{1}{562}$ of a second—1125 being taken as the velocity of sound per second. By the time the first reflection has reached the ear, a second portion of the impulse has reached the third bar, and by the time the second reflexion reaches the first bar, the time elapsed will be $\frac{2}{1125}$ or $\frac{1}{562}$ of a second. The next repetition of the sound will be after it has travelled to the fourth bar and back again, a distance of six feet, occupying $\frac{3}{1125}$ or $\frac{1}{375}$ of a second, and so on throughout the whole series; so that if we had 562 such bars, we should receive an echo from the surface of every one of them exactly in one second of time, or 562 sounds in a second, with equal intervals between them. Now nothing farther than this is required to produce a musical tone, or one depending on equal and frequently repeated intervals. Accordingly we should find that our series of palisades or railings would yield the note D, rather more than an octave above the middle C of the piano-forte.

It is a principle similar to this that we are to explain the *rolling* noise of thunder. The lightning flash, which accompanies thunder, but which seems to us to occur earlier, on account of the great velocity of light, is over in an instant, whereas the rolling of thunder continues for several seconds after the flash has disappeared. This is attributed to the particular positions which the cloud may occupy with respect to the observer. Clouds may be placed at various distances from him, so that the echo of the report resulting from the thunder reaches his ear at different instants, according to the distance of the cloud whence it is reflected. One cloud may be at such a distance that the report may be echoed in five seconds, a second report in six seconds, and so on; and thus may arise those successive sounds which we denominate the "rolling" of thunder.

Our space will not allow us to enter largely into details respecting terrestrial echoes. It must suffice to say that there are many spots, both naturally and artificially contrived, where sound is perfectly reflected as to produce remarkable echoes*. The Lake of Killarney, Woodstock Park, St. Alban's Church, Shipley Church in Sussex, the Cathedral of St. Paul, and Gloucester Cathedral, are some of the localities and buildings in our own land which have acquired celebrity on account of their echoes. It may, however, be well to describe somewhat in detail a celebrated spot on the banks of the Rhine, which yields a remarkable echo, and a view of which we have chosen for our frontispiece. This is the *Lurleyberg*, or Lurley rocks, on the banks of the Rhine between Ehrenbreitstein and Johannisberg, not far from Oberwesel. The river flows between lofty cliffs which wind in a peculiar manner in such a way as to afford multiplied reflexions of sound. Mr. Fearnside, in Tombleson's *Views on the Rhine*, makes the following remarks on the subject:—"The river now making a sharp turn, sweeps with a more expanded and rapid current round the base of the large basaltic rock of Lurley, called Lurleyberg, celebrated for producing one of the most remarkable echoes in Europe. The echo is stated to have lost in the lapse of years the strength of its reflective powers, which may have arisen from masses of rock having at different periods been detached and fallen into the Rhine; much however depends on the state of the atmosphere, for if too dry or too moist, the reverberation will be materially altered. The blast of a bugle, the report of a pistol or gun, or a holloa, are repeated distinctly five times. The best position for the production of the echo is either in the middle of the stream or on a small promontory on the right bank. Barthius mentions the celebrity of the echo in his notes on the Thebaid of Statius; and Marner, in the reign of Frederick the Second, wrote a poem, in commemoration. In earlier days, the real cause of echo being unknown, many whimsical reasons have been assigned for its origin by the ancients. Hence many legendary accounts have been given of the echo of the Lurleyberg."

4. Resonance and Sympathetic Vibration.

When treating of the vibration of a column of air, we stated that the tone or pitch of the sound resulting from such vibration depends altogether on the length of the column, without regard to its diameter. But there is a limit to the applicability of this principle: for it is found that when the diameter becomes nearly equal to the length, the note elicited is rather flatter in pitch than when the diameter is smaller. The term *resonance* has been applied to the tone emitted under such circumstances, to distinguish it from the tone emitted from narrow columns of air; thus we speak of the *tone* of a pipe or tube, and the *resonance* of a box, or cavity, or a mass of air of which the three dimensions approach to an equality.

This being premised, we may state generally that every cavity, whatever be its form, has, when filled with air, a resonant tone belonging to it,—a tone which, other things being equal, is constantly the same. Thus, a large shell being held to the ear, a low musical hum or roar is heard, which is the resonance of some particular tone among the innumerable sources of sound which everywhere surround us. If we take a hollow cavity of any description whatever, and placing the mouth at the orifice, shout or speak loudly, we shall find that the cavity will respond, as it were, to one particular note more than any other, and will reinforce the sound of the voice in an extraordinary degree, when that note is produced.

Resonance is often confounded with echo; but the two phenomena are essentially different. An echo is totally indifferent to all variations of pitch; all sounds travel with equal rapidity, and all have the same tendency to be reflected from opposing surfaces. But resonance depends on the comparative length, breadth, and depth of a cavity. It might perhaps be correct to say that resonance is the result of millions of minute echoes from different parts of the cavity; but we know nothing of them except as a whole, which whole is a tone of constant pitch; whereas what we term an echo, is a simple reflexion from one point.

A cavity of any given dimensions yielding a constant tone when the contained air is excited to vibration, Savart has recommended the adoption of cubical organ-pipes, as being more portable than long tubes, and equally certain in their application; a cubic box, whose side measured four and a half inches being found to emit the same tone as a ten-inch organ-pipe. The resonance of cavities has enabled

* The reader will find two amusing and instructive articles on "The Origin and Nature of Echoes," in *Saturday Magazine*, Vol. XIV. pp. 47, 109.

the same distinguished philosopher to detect the existence of nodal or quiescent lines in a vibrating mass of air. For this purpose he constructed a short but wide cylindrical cavity, closed at one end; and over a similar cylinder he stretched a membrane with such a degree of tension that, like the parchment head of a drum, it had a particular velocity of vibration belonging to it. He then procured as a sounding instrument, a glass goblet or harmonica glass; and the whole were so chosen that the resonance of the two cylinders, and the vibrations of the goblet and the stretched membrane, should all produce the same tone. The empty cylinder was then placed horizontally, the harmonica glass placed immediately before its mouth, and the other cylinder placed vertically; so that the membrane itself was horizontal, and in a line with the axis of the horizontal cylinder. In this position everything conspired to increase the intensity of the sound emitted by the glass. If, for instance, the glass when vibrated by a bow yielding a tone due to 500 vibrations per second, the cylinder or cavity before which it was placed, being fitted to vibrate similarly, greatly reinforced the sound by reacting on the mass of air in a right line with the axis of the cylinder. When that agitated air therefore reached the membrane, which was in the prolongation of the axis, it was set into similar vibration, as was shown by the motion of fine sand strewed on its surface; and those vibrations were again strengthened by the under surface of the membrane forming part of a cavity, whose resonant tone was the same as the tone of the membrane.

With this apparatus, Savart detected the extent of the pulses of sound, between each two of which a nodal or quiescent point was situated. When the exploring membrane was situated at any part of a pulse or wave of sound, the sand on its surface was thrown into vibratory action; but when at a nodal point between two pulses, the sand was quiescent.

With this truly philosophical apparatus, M. Savart detected the extent of the pulses of sound, of which we have spoken, between each two of which a nodal or quiescent point is situated, and which depend for their length, on the velocity of vibration, thus: $\frac{1125}{\text{Vel. of Vib.}}$ = length of pulse in feet. When the exploring membrane was situated at any part of a pulse, the sand on its surface was thrown into vibrating action, but when at a nodal point between two pulses, the sand was quiescent, and if the ear, on being placed on one side of a node nearer to the glass, estimated the sound as emanating from the glass, it would, if placed at an equal distance on the other side of the same node, refer the production of the sound to precisely the opposite quarter; thus proving as was before shown, that the particles of air, in two adjoining pulses, are moving in opposite directions, at the same moment. These phenomena relate to a line coincident with the axis of the horizontal cylinder; but a series of nodal lines was detected in various parts of the apartment, even through an open window, to a considerable distance.

The whole principle of sounding-boards, on which so much of the effect and beauty of musical instruments depends may be referred to that kind of resonance to which the term "sympathetic vibration" has been applied. The strings of a violin are stretched across a bridge, pressing on a broad thin wooden surface, and the pressure of the bow on the strings, by stretching them out of their longitudinal direction, gives a minute but rapid rocking motion to the bridge, which motion is communicated by the bridge to the body of the violin whereon it rests, and the whole upper surface of the violin vibrates with the string. But this is not all. A sounding-peg, placed nearly under the bridge, communicates those tremors to the lower surface of the violin, and the two surfaces together excite the resonant power of the air, in the cavity inclosed between them. Thus we see that the tone emitted by the string receives augmentation and enrichment from three different sources,—the upper surface of the violin, the lower surface, and the air between the two. Savart has shown that if fine powder be strewed on the surface of a violin, it would be thrown into different forms according to the note produced on the string; thus showing that although the body of the violin vibrates with any tone produced, it does not vibrate as a whole from side to side, or from end to end, but divides into separate vibrating portions, separated by nodal lines, and that the position of those nodal lines varies with the note produced.

A principle of sympathy as relating to sounds is observable in a great variety of phenomena. If a number of drinking-glasses be ranged on a table, and a note be strongly excited on a musical instrument near them, any glass happening to correspond in its vibrations with that note will sound sympathetically with it. Supposing the instrument performed 100 vibrations in a second, the surrounding air would be excited with the same velocity of vibration, and would, in its turn, excite similar vibrations in any third body fitted to that particular velocity of vibration: so also a vibrating body not in unison with other bodies may excite sympathetic sounds in them by separating them into their harmonic divisions. "If two cords, equally stretched, of which one is twice or three times longer than the other, be placed side by side, and if the shorter be sounded, its vibrations will be communicated by the air to the other, which will be thrown into such a state of vibration, that it will be spontaneously divided into segments equal in length to the shorter string. When a tuning-fork receives a blow and is made to rest upon a piano-forte during its vibration, every string which either by its natural length or by its spontaneous subdivisions, is capable of executing corresponding vibrations, responds in a sympathetic note. Some one or other of the notes of an organ are generally in unison with one of the panes, or with the whole sash of a window, which consequently resounds when these notes are sounded. A peal of thunder has frequently the same effect. The sound of very large organ pipes is generally inaudible till the air be set in motion by the undulations of some of the superior accords, and then its sound becomes extremely energetic. Recurring vibrations occasionally influence each other's periods. For example, two adjacent organ-pipes nearly in unison, may force themselves into concord; and two clocks whose rates differed considerably when separate, have been known to beat together when fixed to the same wall, and one clock has forced the pendulum of another into motion, when merely standing on the same stone pavement."—SOMERVILLE.

A sympathetic sound may be excited in a very pleasing manner by taking a tube closed at one end, and a tuning-fork of such a pitch as shall agree with the tone belonging to the tube. If a wafer be fixed to one prong of the fork, of such a size as exactly to fit one end of the tube, and if the fork be vibrated and held with the wafer immediately over the tube, the tone will be reinforced with great richness, because the column of air in the tube is just the length to vibrate with the fork. If the tube and the fork be not tuned in unison, the sound will be reinforced, but not in so great a degree; in this instance the column of air in the tube is forced into a velocity of vibration different from that which properly belongs to it.

Professor Wheatstone has availed himself of the principle of sympathetic vibration to produce a musical performance of a very remarkable kind. Some years ago this gentleman transferred the whole of the musical effects produced by an orchestra to a piano-forte placed at a considerable distance. A sounding-board (which is merely a large surface capable of vibrating perpendicularly to its own plane) was placed near the orchestra in such a position as to resound to all the instruments. A metallic rod was made to touch the sounding-board, and, at the other end, was brought into contact with the sounding-board of a piano-forte. Professor Wheatstone observes, "The effect of this experiment is very pleasing; the sounds indeed, have so little intensity as scarcely to be heard at a distance from the reciprocating instrument; but in placing the ear close to it, a diminutive band is heard, in which all the instruments preserve their distinctive qualities; and the pianos and fortes, the crescendos and diminuendos, their relative contrasts. Compared with an ordinary band heard at a distance through the air, the effect is as a landscape seen in miniature beauty through a concave lens, compared with the same scene viewed by ordinary vision through a murky atmosphere. It is instructive to mark the steps whereby this is brought about. The instruments in the orchestra excited vibrations in the air, these were communicated to the sounding-board, from that through the metallic rod, then to the sounding-board of the piano-forte, then again to the stratum of air between the latter and the strings, and lastly to the strings themselves.

END OF THE TWENTIETH VOLUME.

LONDON Published by JOHN W. PARKER, West Strand, and sold by all Booksellers.